MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2018/2019

ENT3076 – NANO-SCIENCE

(NANO)

12 MARCH 2019
2:30 p.m – 4.30 p.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please print all your answers in the Answer Booklet provided.

List of Constants

Electron mass in free space, $m_o = 9.11\times 10^{-31}$ kg
One electron volt, (1eV) = 1.60×10^{-19} J
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Reduced Planck's constant, $\hbar = 1.05 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K
Permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-14}$ Fcm^{-1}

List of Formulas

$$n = 1 + \sqrt{\frac{2m^* V_b L^2}{\pi^2 \hbar^2}}$$

$$\varepsilon_{n1,n2} = \frac{\hbar^2 \pi^2}{2m^*}\left(\frac{n_1^2}{L_x^2} + \frac{n_2^2}{L_y^2}\right)$$

$$\varepsilon_1 \approx \frac{m^* V_b^2 L^2}{2\hbar^2}$$

$$\frac{\rho}{L} = \frac{1}{\pi}\sqrt{\frac{2m^*}{\hbar^2}} \sum_{n1,n2} \frac{1}{\sqrt{E - \varepsilon_{n1,n2}}} \Theta\left(E - \varepsilon_{n1,n2}\right)$$

$$\frac{\rho}{S} = \frac{m^*}{\pi\hbar^2} \sum \Theta\left(E - \varepsilon_n\right)$$

$$N_t = \frac{2\sqrt{2}m^{*\frac{3}{2}}}{3\pi^2\hbar^3} |V_b|^{\frac{3}{2}} L_x L_y L_z$$

$$j = e\left(\mu_B n_B d_B + \mu_W n_W d_W\right)\frac{F}{d}$$

$$v_z = \sqrt{\frac{2\varepsilon}{m^*}}$$

$$\Gamma = \left(T_l + T_r\right)\frac{v_z}{2L_w}$$

$$\Gamma = T\frac{v_z}{2L_w}$$

Continued ...

Question 1

As a product engineer, you fabricated a light emitting diode with quantum well structure using 8nm-thick Gallium Arsenide (GaAs) and 100nm-thick Aluminum Nitride (AlN). Table Q1 listed the basic parameters of GaAs and AlN.

Table Q1

Material	Electron Affinity	Energy Bandgap	Electron Effective Mass	Hole Effective Mass
GaAs	4.07eV	1.42eV	0.063 m_o	0.51 m_o
AlN	0.60eV	6.03eV	0.40 m_o	7.20 m_o

(a) (i) Calculate the number of subband energy for electrons. [4 marks]

(ii) Calculate the first, second and third energy subbands for holes confinement. [6 marks]

(iii) Determine the emitted wavelength of the light emitting diode if an electron drops from second energy subband in conduction band to second energy subband in valence band. [5 marks]

(iv) Calculate the density of states per unit area for holes if the total energy of hole gas in the quantum well is 0.07eV. [4 marks]

(b) With the aid of diagrams, briefly differentiate Mott-Wannier excitons and Frenkel excitons. [6 marks]

Question 2

(a) Figure Q2(a) shows the reciprocal lattice for Material Q2. Give the definition of Brillouin zone and sketch the first, second and third order reduced Brillouin zones of the reciprocal lattice for Material Q2. [8 marks]

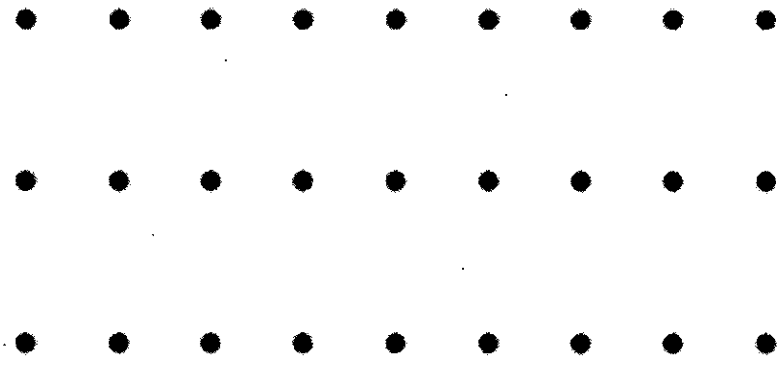

Figure Q2(a)

Continued ...

(b) With the aid of Figure Q2(b), briefly explain the changes of bandgap for Ge_xSi_{1-x} alloy. What is the importance of semiconductor alloys? [7 marks]

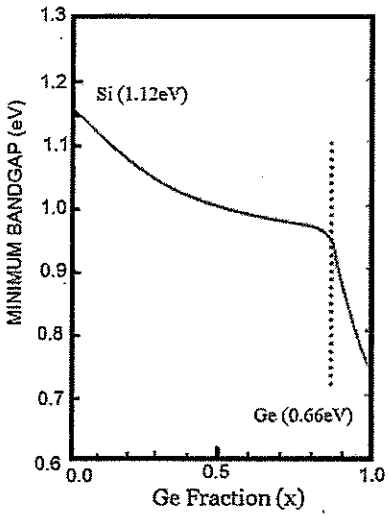

Figure Q2(b)

(c) Material XX and YY are used to fabricate a quantum well structure YY/XX/YY. Table Q2 listed the basic parameters of materal XX and YY.

Table Q2

Material	Electron Affinity	Energy Bandgap
XX	1.5eV	2.3eV
YY	5.6eV	0.9eV

(i) Calculate the band discontinuity of conduction band and valence band for quantum well structure YY/XX/YY. [2 marks]

(ii) Sketch the quantum well structure YY/XX/YY and label clearly band discontinuity, bandgap, electron affinity and materials in the diagram. [6 marks]

(iii) Identify the quantum well structure YY/XX/YY is either straddling, staggered or broken gap. Justify your answer. [2 marks]

Question 3

(a) With the aid of diagrams, differentiate parallel and perpendicular electron transport in a quantum wire. [6 marks]

Continued ...

(b) A 8nm-thick GaA is sandwiched with two 50nm-thick AlN layers to form a quantum well. This quantum well is applied with electric field and parallel electron transport happens. Given that electron mobility in GaAs and AlN are $8500cm^2V^{-1}s^{-1}$ and 300 $cm^2V^{-1}s^{-1}$, respectively.

(i) Calculate the total current density when electric field at 1kV/cm and electrons flow in GaAs at concentration of $3\times10^{16}cm^{-3}$. [3 marks]

(ii) Calculate the total current density when electric field at 1.5kV/cm and concentration of electrons flow in GaAs drops to $2.4\times10^{16}cm^{-3}$. [3 marks]

(iii) Explain the difference of total current density in part (i) and (ii). [5 marks]

(c) A diode with 10nm-thick of GaAs is fabricated as shown in Figure Q3(c).

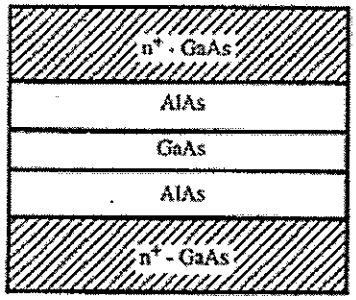

Figure Q3(c)

(i) Name the fabricated device. [1 mark]

(ii) Assume that the electron energy $E_\perp$ is exactly coincides with the first subband energy at 70meV, calculate transverse velocity of the electron in the well, v_z. [3 marks]

(iii) Calculate the tunneling probability per unit time, Γ, if the structure has a symmetry barrier. [2 marks]

(iv) Calculate the tunneling probability per unit time, Γ, if the structure has an asymmetry barrier with two different transmission coefficients of 0.45 and 0.3, respectively. [2 marks]

Question 4

(a) With the aid of diagrams, explain the working principles of a double barrier resonant tunnelling diode. [9 marks]

Continued ...

(b) A quantum well structure is used to fabricate a light emitting diode. First subband energy for electron and hole are 0.04eV and 0.02eV, respectively. Energy bandgap for active layer is 1.12eV.

(i) Define selection rules for electron transition in quantum well. [4 marks]

(ii) According to selection rules for electron transition, determine the first **THREE** wavelengths that can be emitted by the light emitting diode. [6 marks]

(c) Variations of the carrier concentration induces significant changes in the absorption coefficient in the quantum well as a result of the **TWO** main mechanisms. Briefly explain these two mechanisms. [6 marks]

End of Paper.